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Huntsville Division

AD-A165 622

EXPLOSION DAMAGE ASSESSMENT AND STRUCTURAL INTEGRITY EVALUATION

MILAN ARMY AMMUNITIC[illegible] [illegible]LANT
LOAD ASSEMBLY AND F[illegible]
BUILDING A2

HNDTR 85-70-SD-SE
OCTOBER 1985

Unclassified

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An accidental explosion involving 18 lbs of Composition A5 occurred in an operating M42 grenade pressing line. The explosion initiated in a remotely controlled press housed in a cubicle with one venting wall; the remaining three walls and roof were hardened. The cubicle was constructed in accordance with TM 5-1300 and was located within a conventionally designed and constructed steel frame building with a cement asbestos roof. The cubicle performed in accordance with the original design criteria. No significant cubicle structural damage or hazardous spalling occurred. Reuse of the cubicle was

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) possible with minor repairs. Overpressure substantially damaged the brittle roof material. The building frame suffered only minor damage. The cubicle defeated fragments and sufficiently attenuated overpressures such that only minor injuries occurred. Personnel whole body displacement and eardrum type injuries were consistent with the blast pressure attenuation expected for this type cubicle configuration. The roof was replaced with a frangible aluminum roof and the cubicle walls and roof refinished using epoxy mortar grout. The cubicle performed as intended and design methods and blast pressure prediction procedures agreed well with actual events.

EXPLOSION DAMAGE ASSESSMENT AND STRUCTURAL INTEGRITY EVALUATION

Milan Army Ammunition Plant
Load Assembly and Pack
Building A2

Prepared by

U.S. Army Engineer Division, Huntsville

HNDTR 85-70-SDSE
October 1985

TABLE OF CONTENTS

LIST OF FIGURES

TABLE OF CONTENTS (cont)

LIST OF FIGURES (cont)

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1-1. BACKGROUND

a. Accidental Detonation. On 1 April 1985 at approximately 8:20 a.m. an accidental explosion occurred at Milan Army Ammunition Plant (MAAP) in Building A2 of Line A. The source of the event was a feed hopper serving an M42 grenade pressing operation. It was estimated that the feed hopper contained approximately 18 pounds of Composition A5. The pressing operation was located in a reinforced concrete cubicle located on the east side of the building. The incident caused the blowout failure of the frangible exterior wall of the adjacent service ramp, as well as the failure of a large area of the cement asbestos roofing over the main area of the building behind the cubicle. There was no significant structural damage to the building framing or the press cubicle. There were 45 personnel operating in the building at the time of the incident and only two minor injuries occurred, neither requiring hospitalization. Replacement of the roofing was completed on 11 April and refurbishment of the press cubicle was completed by the end of June 1985.

b. Facility History. Building A2 of Line A at MAAP is a 1940's vintage structure. It consists of steel roof trusses on steel columns as its main framing system, with a cement asbestos (transite) roof and clay tile block infill walls. The building was upgraded in 1980 to accommodate the 8-inch M509 Load Assembly and Pack (LAP) activity currently housed there. The principal elements in the building upgrade included the addition of reinforced concrete cubicles to house the hazardous press operations and enclosing exterior service ramps on both sides of the building. The press cubicles were designed in accordance with TM 5-1300 and were to provide protection to operating personnel from primary overpressure and fragment hazards originating in the press cubicle. Management of the design modification contract and technical review of the blast design was performed by the U.S. Army Engineer Division, Huntsville (USAEDH).

1-2. PURPOSE AND SCOPE

USAEDH was requested by MAAP to perform a damage assessment and structural integrity evaluation of the MAAP facility after the blast incident and to estimate the magnitude of the blast effects to which personnel in the building may have been exposed. To meet this objective the following tasks were performed:

(1) Structural damage survey.

(2) Prediction of blast effects.

(3) Evaluation of structural integrity.

(4) Assessment of personnel protection provided.

Each of these tasks will be addressed in following sections and will be followed with appropriate discussion and conclusions.

1-3. REFERENCES

References can be found in appendix A at the end of the document.

CHAPTER 2

STRUCTURAL DAMAGE SURVEY

2-1. BUILDING

A detailed inspection of the overall condition of Building A2 was performed within a few days of the incident. The results of this inspection were favorable to a relatively simple replacement of roofing and siding. Figure 2-1 presents a plan view of a portion of the A2 building showing the area where the donor cubicle was located and designates the direction in which photographs presented as figures 2-2 through 2-5 were taken. (Figures are compiled at the end of chapter 2.) As can be shown in the pictures, the building damage was essentially limited to wall cladding and roof decking. The wall cladding on the east side of the ramp was intended to be a frangible or blowout-type wall designed to fail quickly and vent the shock and gas pressures from the adjacent cubicles. Figure 2-3 clearly shows large sections of the lightweight frangible aluminum ramp wall panels which performed as intended. The bulk of the remaining damage was the failure of the brittle transite roof decking material. The extent of this damage is exemplified in figures 2-2 through 2-4. This material is very brittle and tends to break up into relatively small pieces under low overpressures. It should be noted that the the roofing on the right side of figure 2-4 had already been removed by repair crews and does not represent damage from the incident. The only damage to structural load-carrying members involved two roof deck support beams directly in front of the donor cubicle. These members were twisted sufficiently that replacement was justified. With the exception of these members, the structural framing system was in excellent condition and immediately capable of accommodating the new wall and roof decking materials.

2-2. PRESS CUBICLE

The donor press cubicle was designated A3 as shown in figure 2-1. Figure 2-5 shows a frontal view of the cubicle, looking west. This cubicle was designed in accordance with TM 5-1300 for 25 lbs of Composition A5. Close examination of the cubicle indicated that it was in excellent condition. There was no exterior spalling of any of the walls. There was a limited area of spall/scab on the exterior of the roof directly above the feed hopper. This was a result of a direct airblast shock being transmitted through the roof slab. However, the concrete spall was still attached to the roof as shown in figures 2-6 and 2-7 and could not be broken loose without the use of tools. While flexure tensile cracks were observed as expected for an internal explosion, they were neither extensive nor large. Figures 2-8 through 2-11 show some of these typical cracks. Preliminary stringline measurements revealed that only very limited inelastic deformation had occurred and only within a short distance of the open end of the cubicle. There was absolutely no evidence of any compression zone distress of concrete section which would indicate significant damage. The fact that observed tensile cracks had not formed classical yield line patterns further suggested very limited response. Following the initial inspection the cubicle walls were sandblasted to remove paint, filler, and sealant. The appearance of the cubicle after sandblasting was consistent with the initial observations. In addition, the spall/scab area on the roof was removed until sound concrete was reached. Internally the principal damage to the cubicle was cratering due to high velocity primary fragments from the press tooling. The main cratering damage was localized over several well-defined regions as shown in figures 2-12 and 2-13. The maximum depth of these spall craters did not exceed two inches in any location and was generally less. It was judged based on the initial inspection that the cubicle could be repaired using epoxy grouts or high strength mortars. This evaluation has been confirmed by analysis based on material properties obtained from nondestructive testing of the actual cubicle.

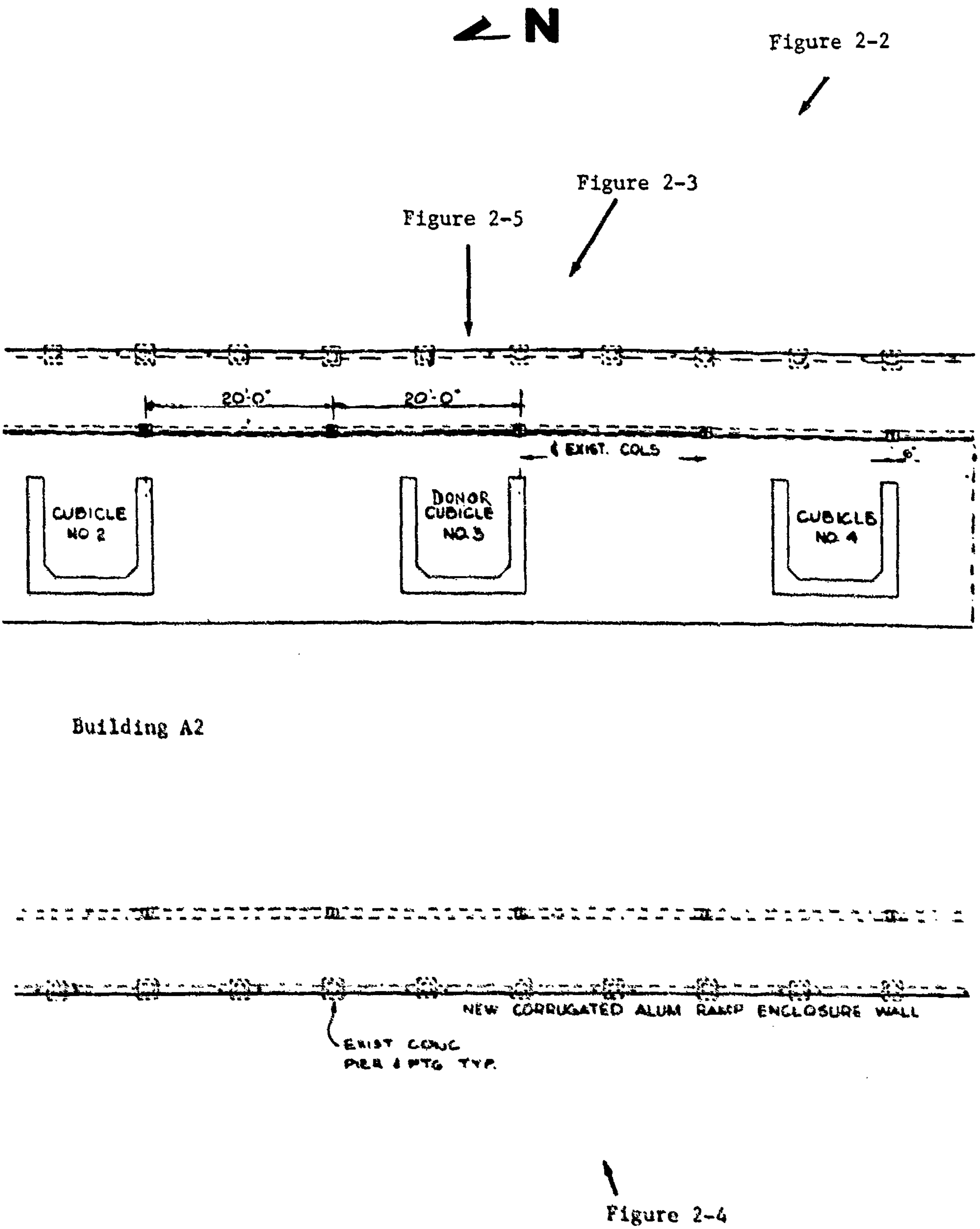


Figure 2-1. Plan View of a Portion of Building A2

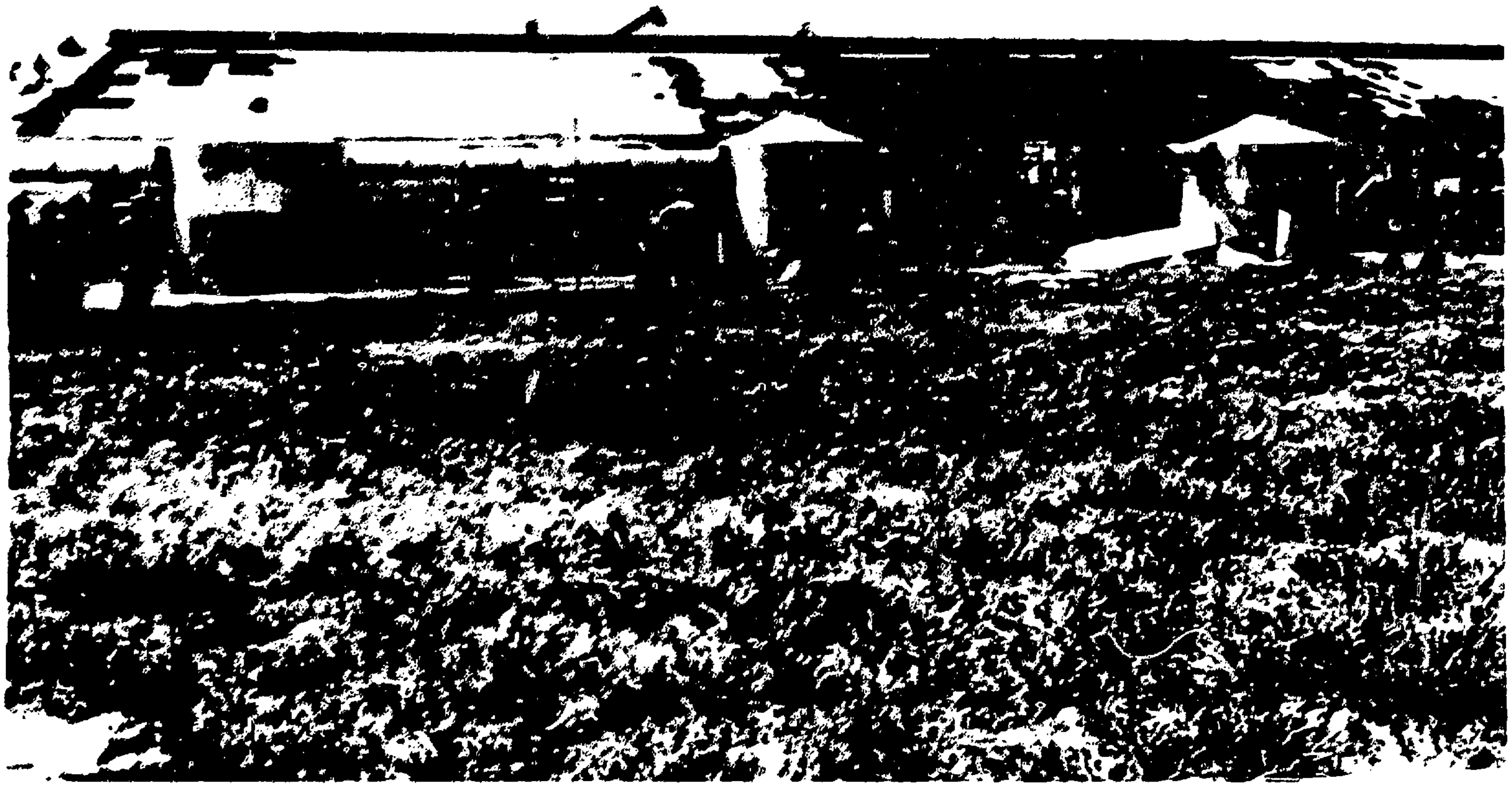


Figure 2-2. East Elevation of Overall Building

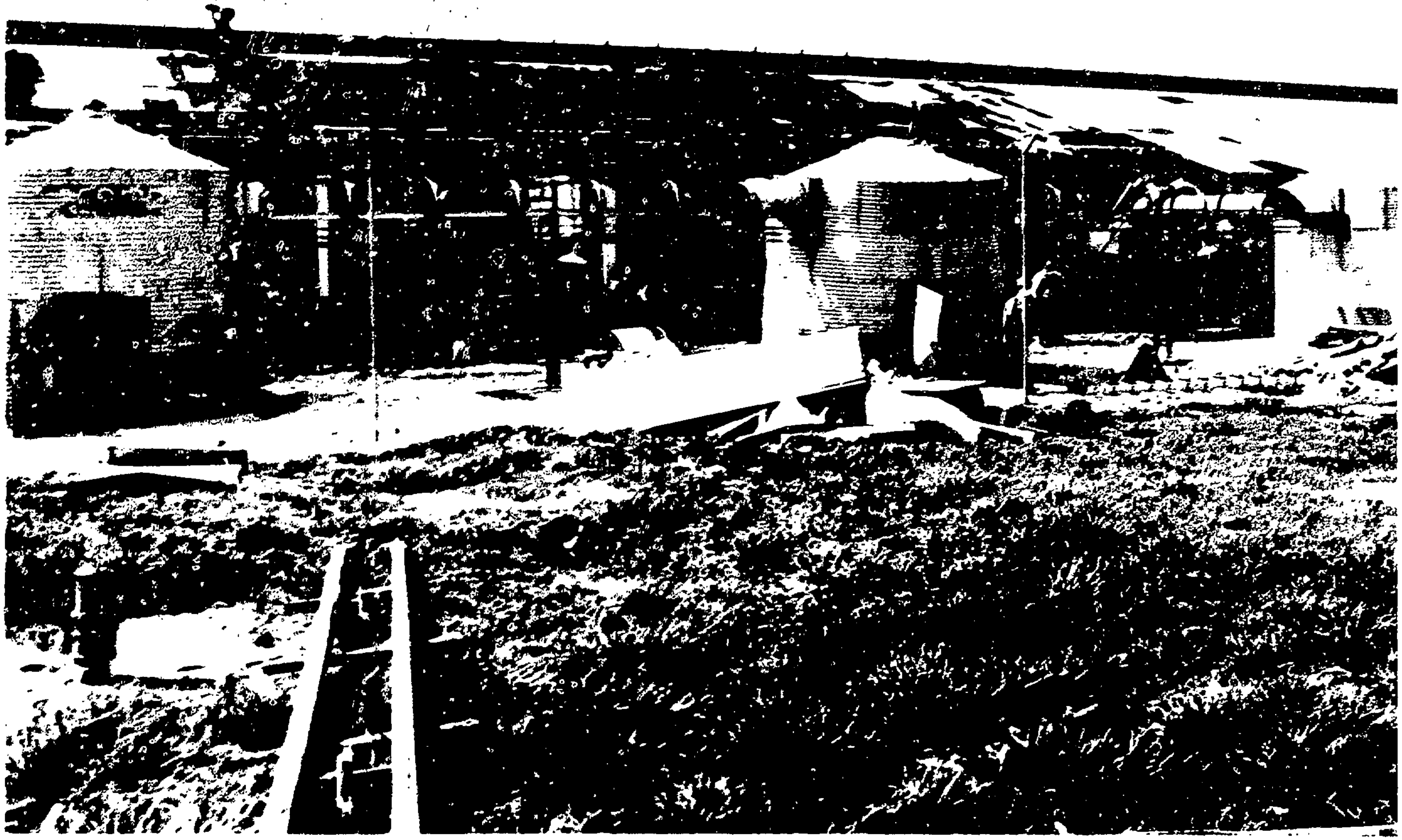


Figure 2-3. East Elevation Ramp Damage

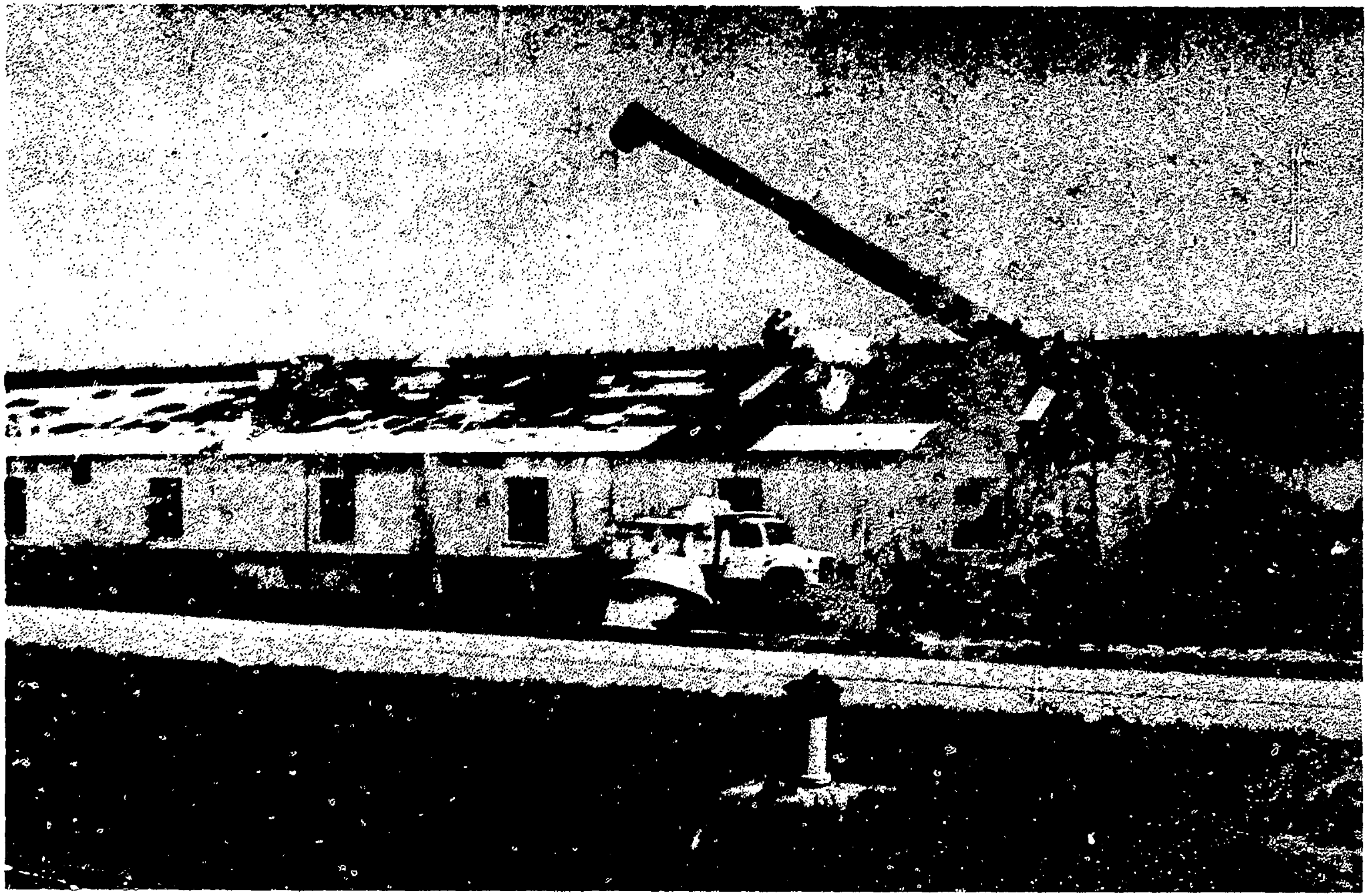


Figure 2-4. West Elevation of Overall Building

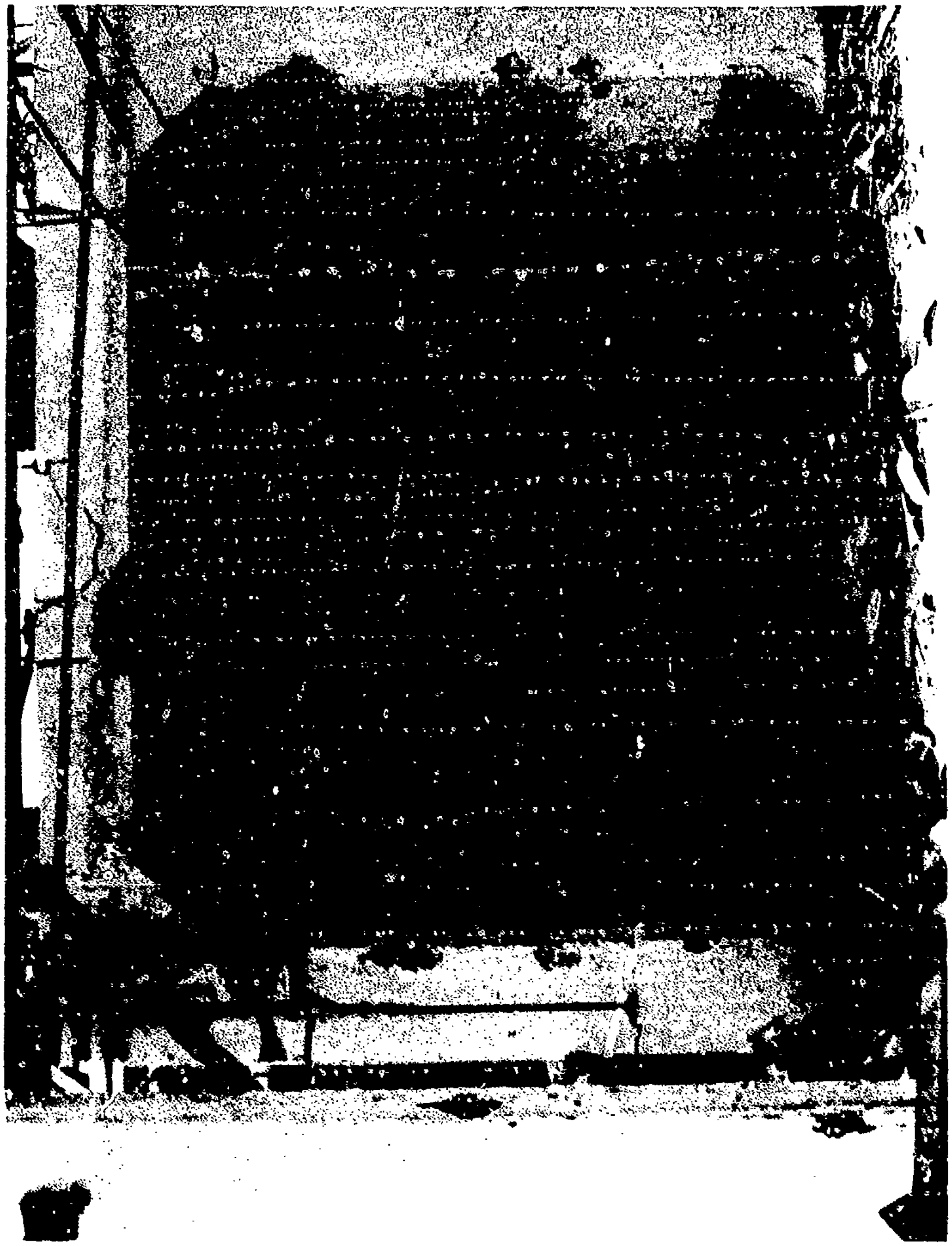


Figure 2-5. Donor Cubicle

Figure 2-3. Edge of Roof Slab Donor Cubicle

Figure 2-7. Cubicle Roof Looking East

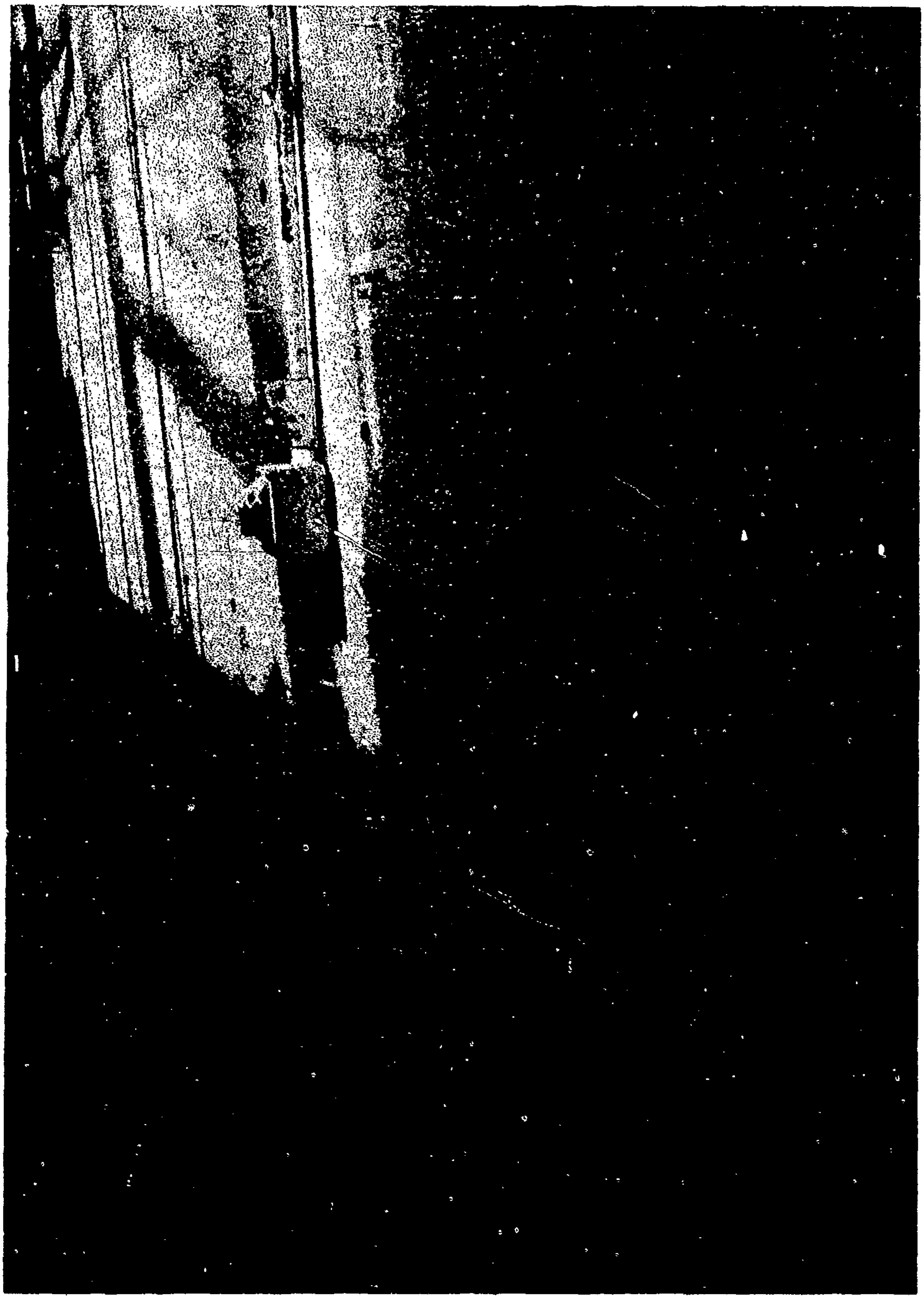


Figure 2-8. Left Wall

Figure 2-9. Right Wall

Figure 2-10. Upper Haunch Left Wall

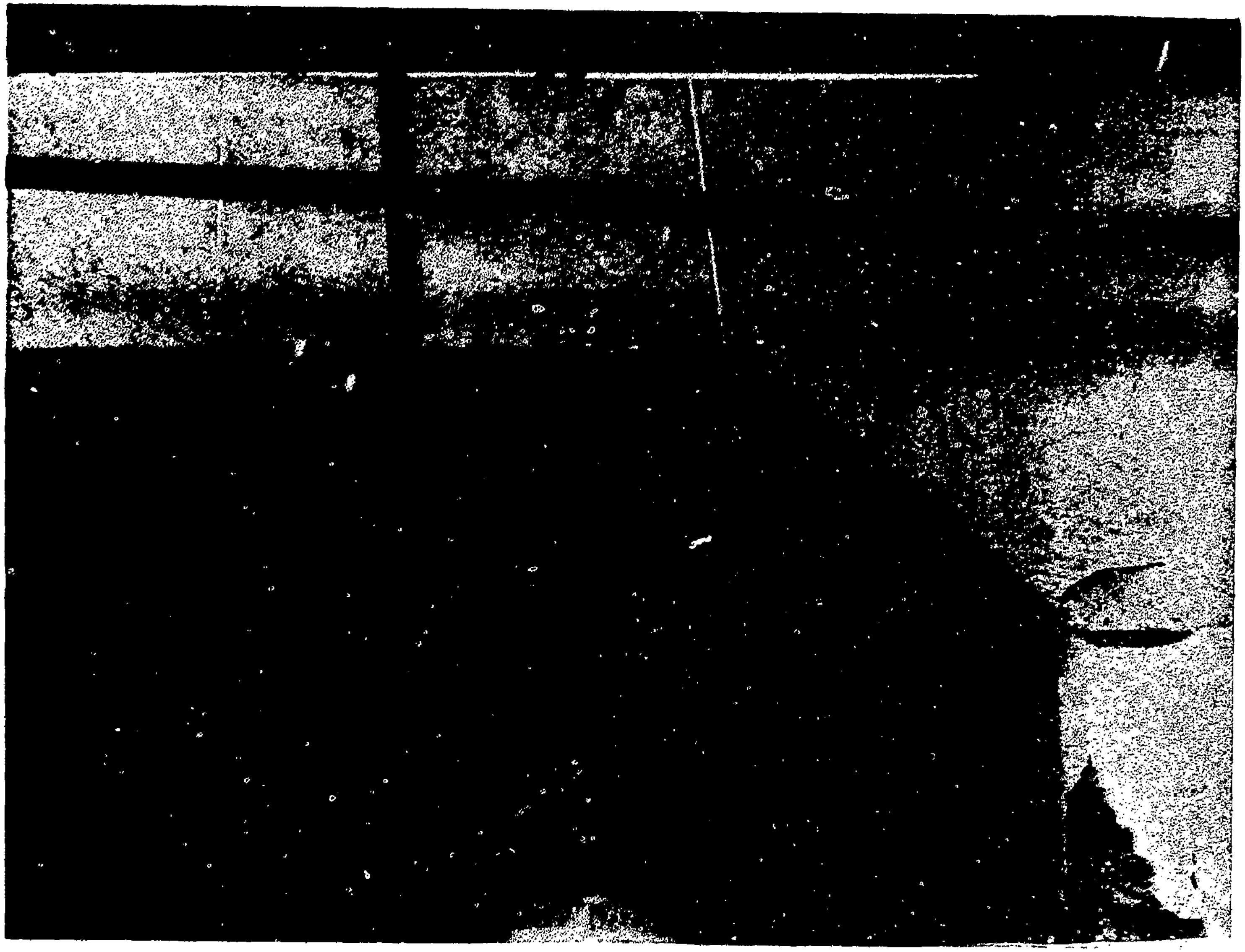


Figure 2-11. Upper Haunch Right Wall

Figure 2-12. Interior Fragment Damage Left Wall

Figure 2-13. Interior Fragment Damage Right Wall

CHAPTER 3

PREDICTION OF BLAST EFFECTS

3-1. LOADS ON THE BUILDING

a. The principal damage to the building system was the destruction of the cement asbestos roofing. This was also the primary area of concern regarding hazards to which operating personnel were exposed. Therefore, the main emphasis in estimating the airblast effects from the incident will be the loads to which the roof and the personnel behind the cubicle were subjected. The determination of probable overpressure loads on the building will be based on airblast parameters given in TM 5-1300 (reference 1) and the methodology developed by Keenan at the Naval Civil Engineering Laboratory (NCEL) (reference 2). This approach has the merit of having been confirmed in part from the testing of an actual building of nearly identical construction to the A2 building (reference 3).

b. The analysis procedure provides for a modification of the scale distance from a donor charge in a cubicle to a receiver. The method accounts for the effect of the cubicle walls and roof in increasing the effective distance from the donor to the receiver. The location of the feed hopper in the cubicle is such that there is some question as to whether the donor charge should be considered a free airburst or a surface burst, the latter being fully reflected. Because of this question, both situations are considered, and estimated overpressures calculated for each. Airblast parameters for the two cases are given in figures 4-5 and 4-12, respectively, of reference 1. Tables 3-1 and 3-2 show the geometric data and resulting airblast parameters for the estimated overpressures on the roof and at an elevation of 5 feet above the floor (for effects on a standing adult). (Tables and figures are compiled at the end of chapter 3 in the order they are mentioned.) Figure 3-1 presents the same results, as expected--upper and lower bounds of overpressure for the roof and the interior of the building, respectively. Figure 3-2 shows the idealized path of the blast wave over the building. There is another path which must also be considered and it is shown in figure 3-3. The results of this load path were found to be no more severe than those of figure 3-1 and are therefore not further considered.

c. The building tested in reference 3 had a roof deck of transite nearly identical to the Milan A2 building. The estimated dynamic capacity of the roof decking in that test was about 6 psi for short duration impulsive loadings. Since the Milan A2 building deck is a slightly longer span it would be expected to fail at a slightly lower load. Predicting the decking failure load at Milan to be approximately 4.5 psi, the information in figure 3-1 suggests that the roof deck within about thirty feet of the cubicle would probably fail. This is consistent with observed damage as shown in figures 2-2 through 2-4.

3-2. BLAST LOADS WITHIN THE CUBICLE

The environment inside the donor cubicle is also calculated on the information in reference 1. The cubicle has one entire wall open to the adjacent service ramp. The ramp was designed with a frangible exterior wall. As a consequence, gas pressure is not a consideration and only shock pressures are considered. The estimated airblast environment within the cubicle is presented in table 3-3. The information shown is similar to the same data in reference 3 for a similar magnitude donor. The information from this chapter is used in chapter 4 to assess the structural integrity of the cubicle for reuse.

Table 3-1. Airblast Loading on Roof
(see notes)

$W^{1/3}=2.71$

ROOF(1) LOCATION	R'(2) (FT)	Z $R/W^{1/3}$	AIRBURST(3) P_{so}	T_0	I_s	SURFACE BURST(4) P_{so}	T_0	I_s
R-1	27	10.0	6.7	5.6	16.7	9.5	6.0	26.4
R-2	35	12.9	4.2	6.4	13.9	6.5	7.2	20.8
R-3	47	17.4	2.7	7.5	10.8	4.0	8.3	16.7
R-4	58	21.4	2.2	8.1	8.9	2.7	9.2	13.6

Table 3-2. Airblast Loading 5 Ft Above Floor
(see notes)

FLOOR(1) LOCATION	R'(2) (FT)	Z $R/W^{1/3}$	AIRBURST(3) P_{so}	T_0	I_s	SURFACE BURST(4) P_{so}	T_0	I_s
F-1	38	14	3.5	6.8	11.6	5.0	7.3	18.9
F-2	38	14	3.5	6.8	11.6	5.0	7.3	18.9
F-3	45	16.6	2.5	7.3	10.0	3.9	8.4	16.2
F-4	54	20	2.3	7.6	8.6	2.7	9.2	12.9

NOTES:
1. See figure 3-1 for locations
2. R'=effective distance determined per reference 2
3. From figure 4-5 of reference 1
4. From figure 4-12 of reference 1

UNITS: P_{so}=(PSI) T_o=(msec) I_s=(PSI-msec)

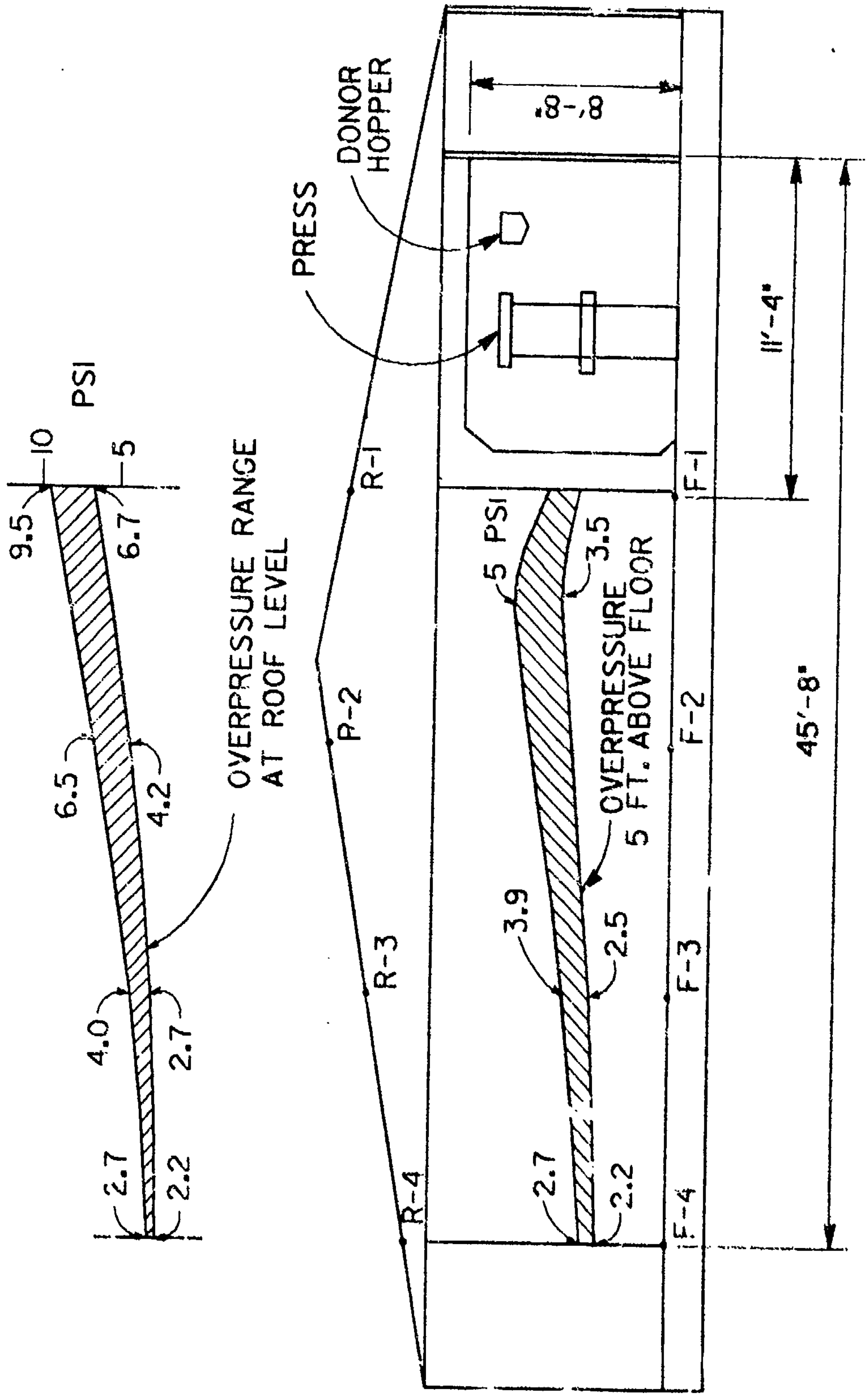


Figure 3-1. Milan Line A Donor Cubicle Overpressures

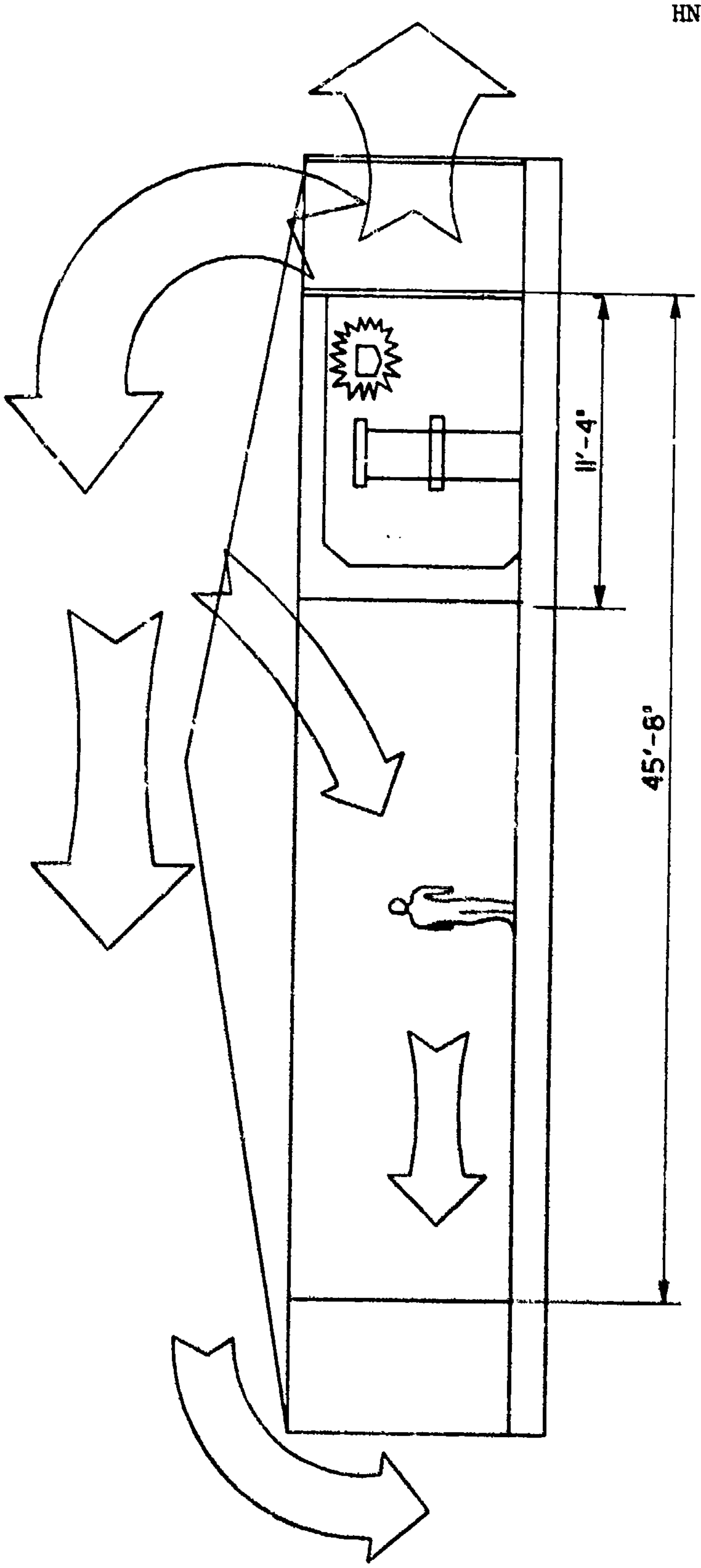


Figure 3-2. Milan Line A Donor Cubicle Blast Path

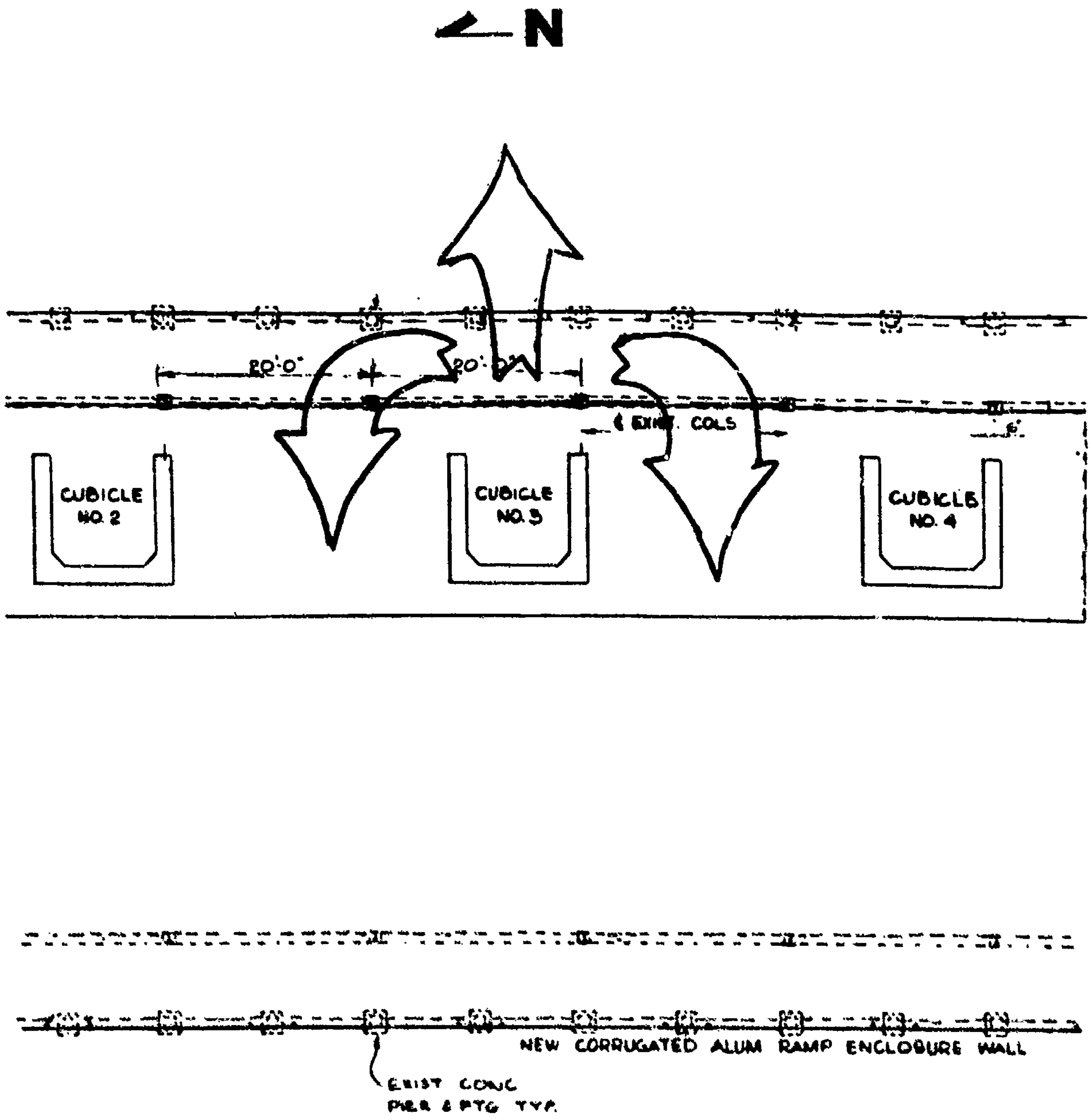


Figure 3-3. Blast Path Exterior to Cubicle

Table 3-3. Blast Environment Within Cubicle

CUBICLE LOCATION (1)	PARAMETER (2)		
	IMPULSE (PSI-ms)	PRESSURE (PSI)	DURATION (msec)
ROOF	566	313	3.6
SIDEWALLS	600	331	3.6
REAR WALL	600	262	4.6

CHAPTER 4

ASSESSMENT OF REMAINING STRUCTURAL SYSTEM

4-1. BUILDING STRUCTURAL SYSTEM

Upon completion of the damage survey and the initial evaluation that the building structural framing system was undamaged and suitable for reuse, a new lightweight aluminum roof decking was installed. This decking was used in place of the former cement asbestos decking which had the undesirable trait during failure of generating large amounts of secondary free falling fragments. However, on the beneficial side, the low failure capacity of the transite assured significant dynamic loads would not be imposed on the roof deck support beams (purlins) or the main building framing. The new aluminum decking has a very low load capacity when limited to a two span configuration. However, the decking actually installed covered four spans. This results in the two interior spans being capable of developing a large deflection membrane resistance after the low flexure capacity is exceeded. It was therefore necessary to assure that the roof purlins were capable of resisting the new loads. Based on the upper bound overpressures determined for the roof in chapter 2, a conservative analysis based on references 1 and 4 confirmed that the roof purlins and trusses could safely resist a similar incident in the future.

4-2. PRESS CUBICLE

Dynamic analyses of the press cubicle walls and roof were performed based on TM 5-1300 (reference 1). The concrete strength used in the analysis was based on the results of the actual in-place compressive strength of the cubicle as determined by nondestructive testing (reference 5). The measured compressive strength values are given in table 4-1, exhibiting the increase in strength with age that is typical of quality concrete. The dynamic stuctural properties of the cubicle based on reference 1 are given in table 4-2. The results of these analyses in terms of predicted maximum deflections and actual measured values at mid-span of walls and roof are shown in table 4-3. It should be noted that the presence of tensile steel at the mid-depth of the concrete elements has a significant influence in limiting the maximum deflection. This steel is normally neglected when designing for flexure. The measured deflections indicate only localized permanent deflections near the open end of the cubicle. The ductility ratios associated with these deflections are within the range considered to be acceptable for reusable structures in TM 5-1300 (reference 1). Repair of the spall damage with a quality epoxy grout will produce a cubicle which is capable of safely resisting a similar incident in the future.

Table 4-1. Measured Compressive Strength (PSI)
(reference 5)

LOCATION	LOWER	MIDDLE	UPPER
LEFT WALL	6870	7000	7000
RIGHT WALL	6155	7460	7000
REAR WALL	6285	7240	7000
ROOF	7000	7000	7000

Table 4-2. Cubicle Dynamic Properties

CUBICLE SURFACE	NATURAL PERIOD (msec)	ULTIMATE RESISTANCE (PSI)	STIFFNESS K_θ (LB/IN)	MASS M_θ (LB-ms^2/IN)
SIDEWALL	5.36	209	3354	2438
ROOF	7.8	169	1462	2271
REAR WALL	5.1	177	3185	2108

Table 4-3. Response

CUBICLE SURFACE	CALCULATED			MEASURED
	2-DEGREE DEFL (IN)	ELASTIC DEFL (IN)	MAXIMUM DEFL (IN)	MAXIMUM DEFL (IN)
SIDEWALL	1.4	0.060	0.221	0.156
ROOF	1.8	0.055	0.236	NONE
REAR WALL	1.68	0.115	0.344	0.25

CHAPTER 5

EVALUATION OF PERSONNEL PROTECTION

5-1. GENERAL

The Milan A2 building was an upgrade of an old structure to accommodate a new process with a hazardous operation. The economics of the project did not allow for hardening the entire building nor did existing safety policy at the time require such action. However, cubicles with hardened roofs and frangible vent walls on the ramp adjacent to the open wall of the cubicle were used to provide the highest feasible level of protection for a building of this type. This section provides an estimate of the probable injury risk which personnel in Building A2 experienced during the incident. Hazards to personnel include overpressure, primary fragments, and secondary fragments. Primary fragments were either confined or directed safely away by the cubicle and were not a consideration for personnel in the A2 building. Overpressure can result in several types of hazard and these will be discussed individually, as will secondary fragments.

5-2. PRIMARY BLAST EFFECTS

Primary blast effects on the human body are related to peak overpressure and specific impulse of the blast wave. The lungs are the most susceptible organs in the body when considering primary blast effects. Figure 5-1 presents data useful in evaluating the risk of lung damage based on incident overpressure and impulse. (Figures and tables are compiled at the end of chapter 5 in the order of their mention.) These curves are extracted from references 6 and 7. Shown also on figure 5-1 is the scaled overpressure and impulse based on the upper bound values in table 3-2. These calculations were based on an assumed body weight of 130 pounds. The results are plotted on the figure and show clearly that for the predicted blast environment in the work area of Building A2, the risk of lung damage is negligible.

5-3. TERTIARY BLAST INJURY

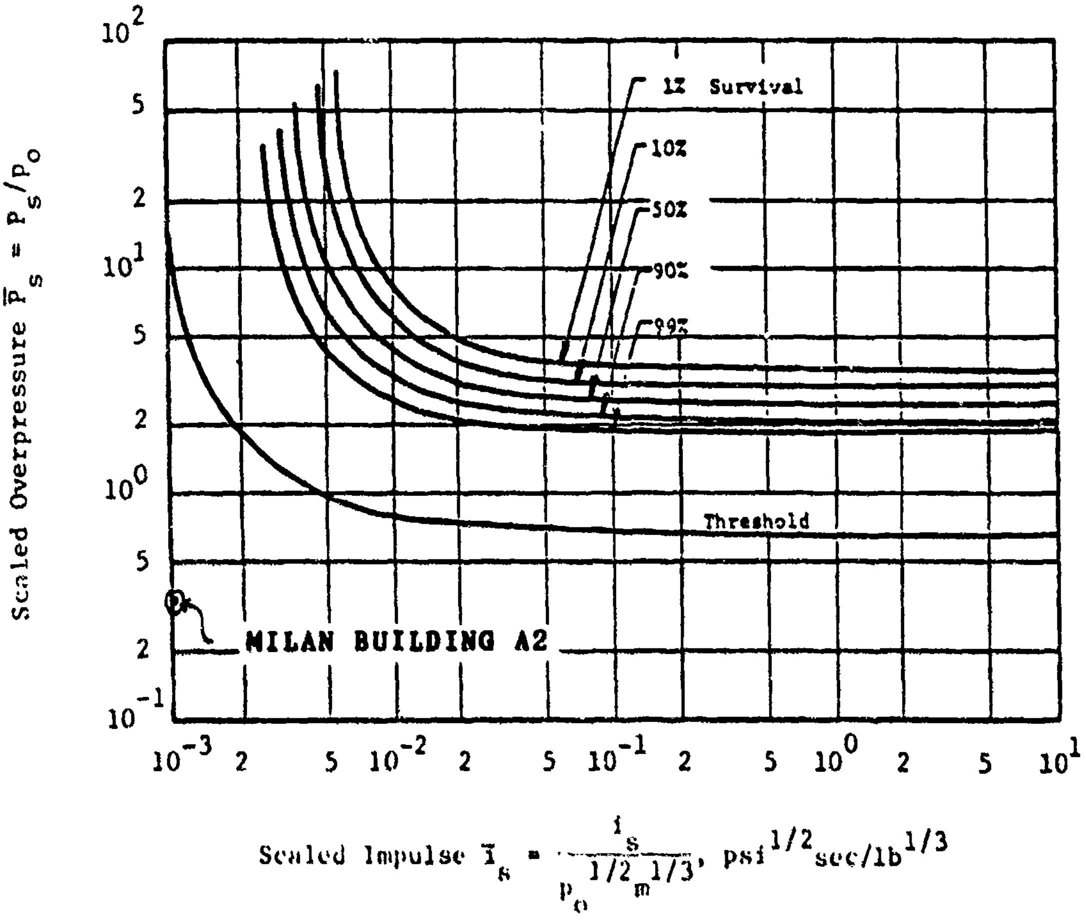
The term tertiary blast injury refers to injuries resulting from whole body displacement. Tables 5-1 and 5-2 present criteria for risk of injury to either the skull or the whole body due to impact at the velocities shown. Although the skull injury tolerance is generally lower, both criteria have the same lower limit "mostly safe" velocity. Figure 5-2 presents the critical velocities in table 5-1 in terms of incident overpressure and impulse. Plotted on this figure is again the upper bound data from table 3-2. Results show clearly that translational forces for the Milan incident appear to be well below those needed to reach a critical velocity.

5-4. EAR DRUM DAMAGE

The human ear is the most sensitive part of the body when considering the effects of a blast wave. An incident overpressure of 5 psi arriving normal to the ear represents the threshold for eardrum rupture. Even lower pressures can cause temporary loss of hearing. The generally accepted "Temporary Threshold Shift" (TTS) is about 2.3 psi (reference 8). These values and the 50-percent rupture pressure are plotted on figure 5-3 in terms of incident overpressure and impulse, along with the upper bound data from table 3-2. This indicates that a risk of at least temporary hearing loss and the onset of eardrum rupture existed at Milan if the head were oriented sidelong to the blast wave.

5-5. SECONDARY FRAGMENT IMPACT

Risks of injuries due to secondary fragment effects at Milan were due almost entirely to the breakup of the transite roof decking which fell into the work area behind the cubicle. Figure 5-4 presents an index, developed in reference 9, of injuries to personnel from secondary fragments. Risk of injury is based on impact velocity and fragment mass. It should be noted that the lower threshold for injuries from fragments greater than 3 pounds is identical to that for tertiary injury given earlier in figure 5-2. The height of the transite roofing above the work area floor varies from about 11 feet at the exterior walls to 21 feet at the center of the building. Assuming unobstructed free fall and neglecting drag, table 5-3 presents free fall time and velocity from the roof to the floor and to 5 feet 6 inches above the floor, respectively. Although a great percentage of the roofing broke into small pieces less than 2 or 3 pounds, there was a sizeable number of larger fragments present. Based on the potential free fall velocities from table 5-3 and the criteria in figure 5-4, there appears to have been a risk of injury from secondary fragments. The minimum risk existed for personnel in the upright position which reduces both the abdominal, thorax, and limb exposure, as well as reducing the probable head injury velocity. Based on the velocities calculated, any fragment larger than 2 pounds would pose a risk. It is interesting to note that a fragment falling from the highest elevation of the roof would have to weigh at least 3.7 pounds to exceed the 58 foot-pound hazardous fragment as defined in DOD 6055.9 (reference 10), which is the most current relatable safety criteria. It should also be noted that the space below the roof and above the work area is very congested with ventilation ducting, piping, conduit, and other items, none of which fell. These items would tend to obstruct the unimpeded free fall of fragments, particularly large ones. This effect may have contributed to the lack of actual fragment impact injuries.



MILAN BLDG A2 $\overline{Ps} = 0.340$

$\overline{is} = 0.001$

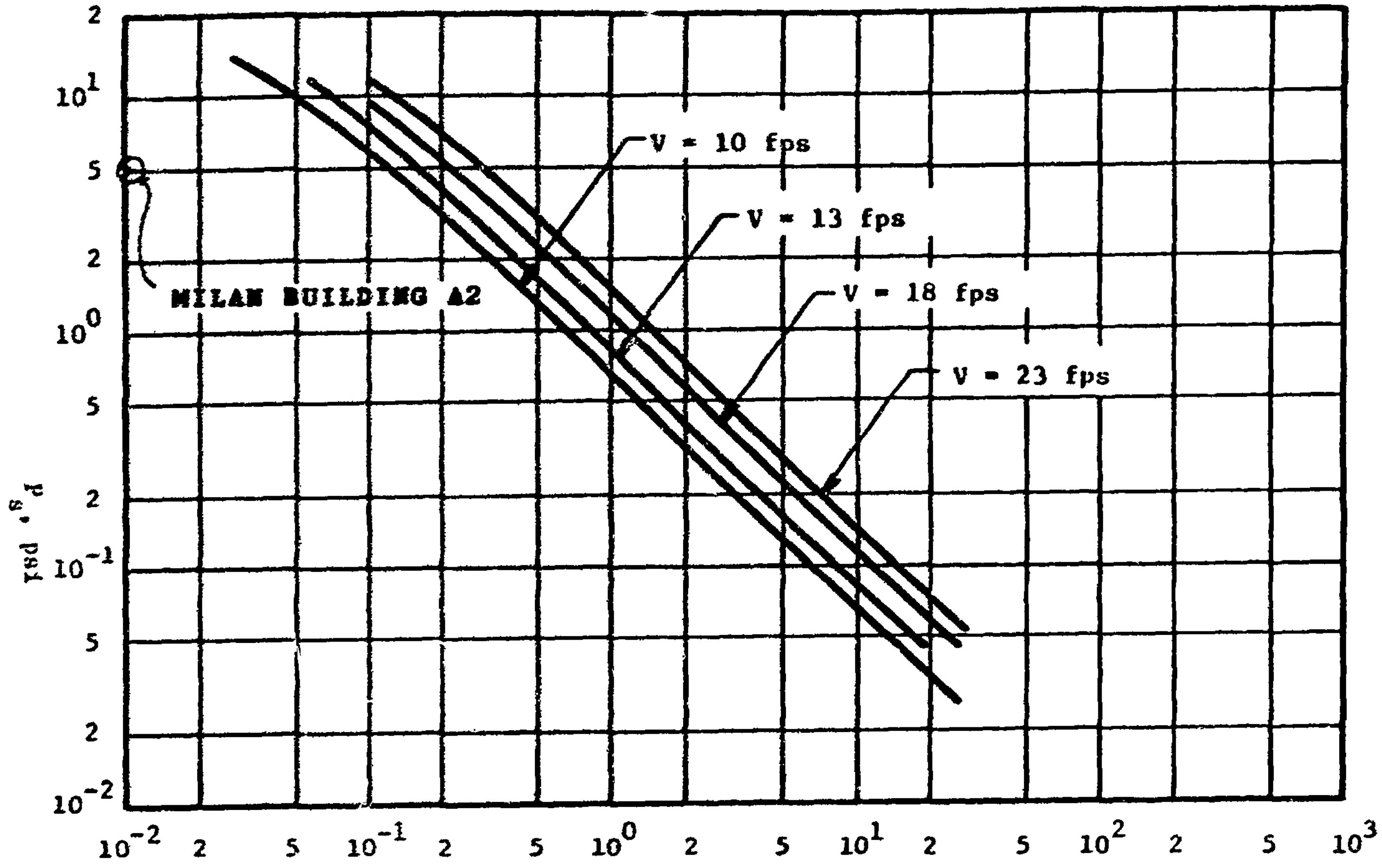
Figure 5-1. Survival Curves for Lung Damage to Man

Table 5-1. Criteria for Tertiary Damage (Decelerative Impact) to the Head (reference 8)

SKULL FRACTURE TOLERANCE	IMPACT VELOCITY FT/SEC
MOSTLY "SAFE"	10
THRESHOLD	13
50 PERCENT LETHALITY	18
NEAR 100 PERCENT LETHALITY	23

Table 5-2. Criteria for Tertiary Damage Involving Total Body Impact (reference 8)

TOTAL BODY IMPACT TOLERANCE	IMPACT VELOCITY FT/SEC
MOSTLY "SAFE"	10
LETHALITY THRESHOLD	21
50 PERCENT LETHALITY	54
NEAR 100 PERCENT LETHALITY	138

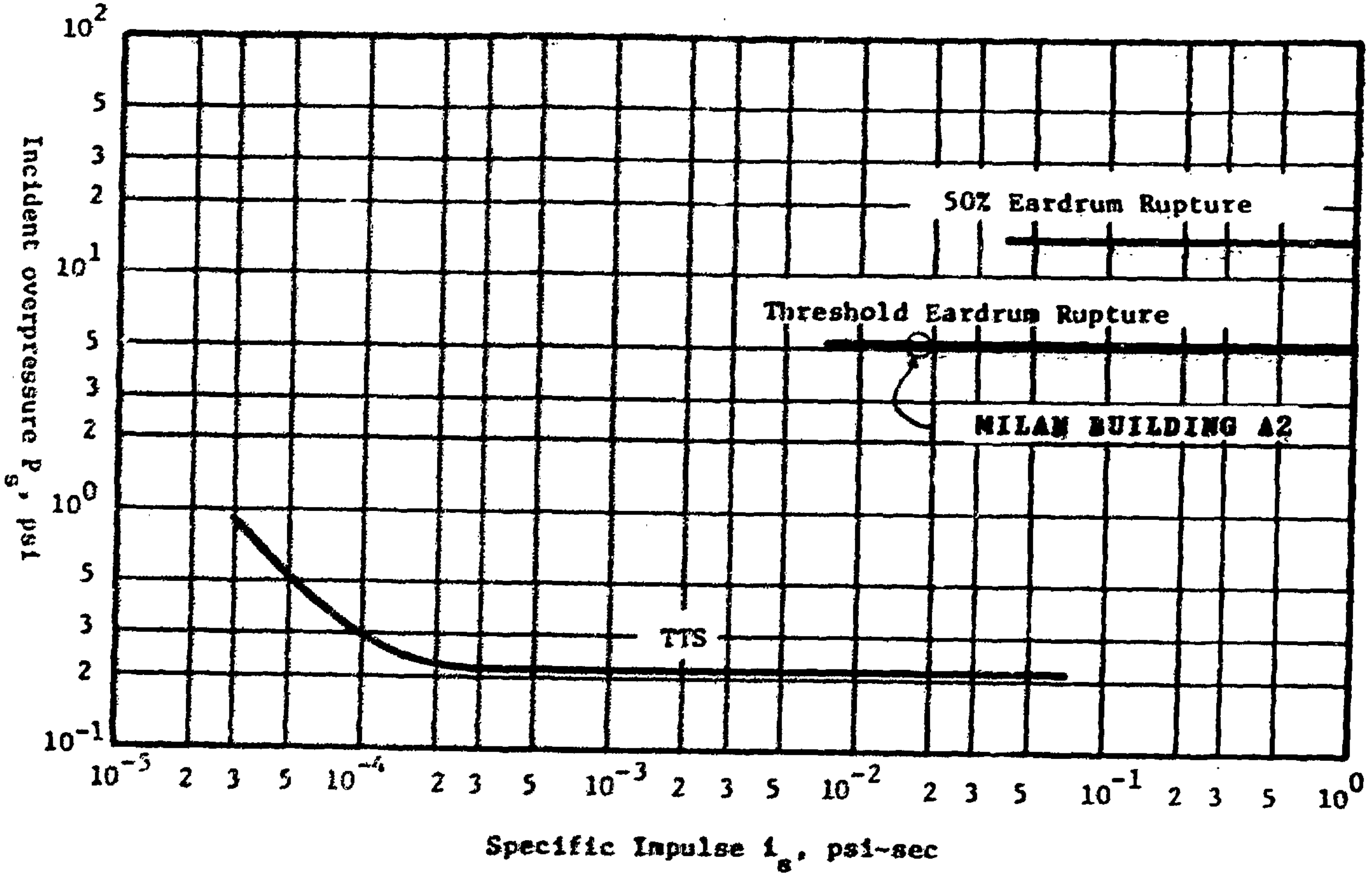


Scaled Impulse $\bar{i}_s = i_s/m^{1/3}$, psi-sec/lb$^{1/3}$

Milan Building A2 Ps=5.0

$\bar{i}$s=0.0037

Figure 5-2. Skull Fracture Risk (reference 8)



Milan Building A2 Ps=5.0

is=0.0189

Figure 5-3. Human Ear Damage Risk for Normal Incidence Blast Waves (reference 8)

Table 5-3. Free Fall Impact Velocities

ROOF HEIGHT	TIME (SEC)		VELOCITY (FT/SEC)	
	TO FLOOR	TO 5'-6" ABOVE FLR	TO FLOOR	TO 5'-6" ABOVE FLR
11	0.827	0.585	26.6	18.8
13	0.898	0.682	28.9	22.0
15	0.965	0.768	31.1	24.7
17	1.027	0.845	33.1	27.2
19	1.086	0.915	34.8	29.5
21	1.14	0.981	36.7	31.6

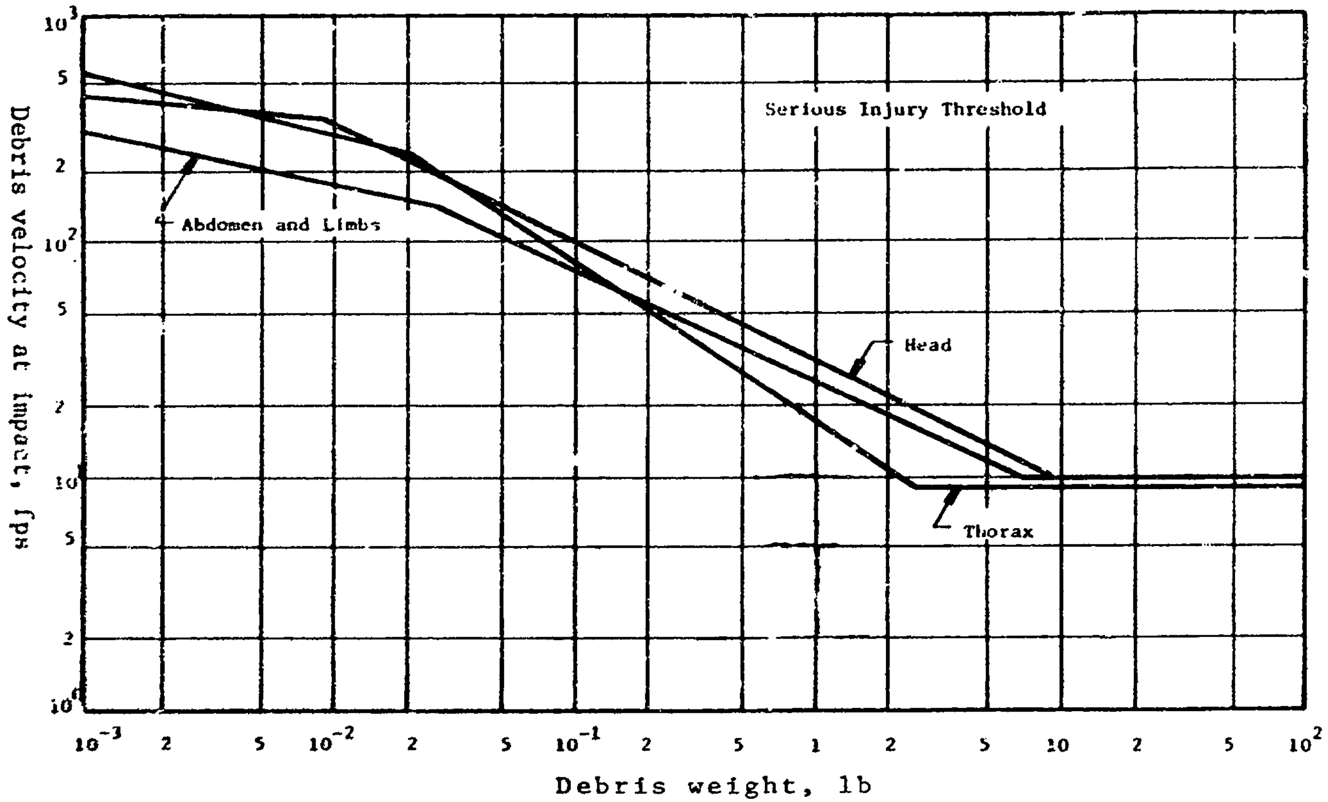


Figure 5-4. Personnel Response to Fragment Impact (Serious Injury Threshold) (reference 8)

CHAPTER 6

DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

6-1. ORIGINAL DESIGN SAFETY CRITERIA

The original criteria used in the modification of the building called for protection of personnel from primary blast and fragment effects (reference 11). Original criteria also proposed a three-wall cubicle with a venting roof. During review of the criteria (reference 12), comments were made by USAEDH regarding protection which such a cubicle was capable of providing to personnel in the building. It was recommended that the cubicles be designed with a hardened roof since this would substantially reduce the overpressures to which the building behind the cubicle would be subjected. However, it was also commented that even a hardened roof would not reduce overpressures on the transite roof sufficiently to preclude failure of the decking. The recommendation for adding the hardened roof to the design was incorporated into the criteria along with several other suggestions. The comments regarding roof deck failure were acknowledged but fiscal constraints resulted in retaining the existing roof. The philosophy followed and accepted by safety review was to obtain the highest possible level of protection within the limitations of the existing building structural system.

6-2. ACTUAL PERFORMANCE OF THE DESIGN

The performance of the cubicle was as expected in the original design. All primary blast and fragments were directed safely away from the operating areas and the hardened roof reduced overpressures behind the cubicles sufficiently to eliminate essentially all risks other than threshold eardrum rupture and secondary fragments. It is significant to note that if the original concept of a three-wall cubicle with a venting roof had been used, the peak overpressure on the roof and behind the cubicles would have been 17 and 11 psi, respectively, and both damage and risk of injury would have increased substantially. The building performance was also aided by the fact that the quantity of explosive involved was less than the design criteria called for and also the concrete strength had increased substantially above the original specified value. In any case the cubicle with a hardened roof is superior to one with a venting roof in terms of reducing pressures behind the cubicle. The overpressures and cubicle shock loads calculated in chapter 3 agree quite well with observed damage at Milan and are also in good agreement with measured data from the full scale building test of reference 3.

6-3. BUILDING A2 AS REPAIRED

The structural framing system is sound and can be expected to perform acceptably for many years.

6-4. PRESS CUBICLE A3

The press cubicles were designed in accordance with TM 5-1300. The explosive event experienced was somewhat less than that used for the original design criteria. This factor along with the substantially higher concrete strength present in the as-built cubicle served to limit damage to low levels. The reinforced concrete sections of all elements have sound compression zones and undamaged reinforcing steel, and have not experienced any significant inelastic deformation. Repair of spall damage using high quality epoxy grout or mortar will provide acceptable surface repair and the cubicle can be expected to successfully contain a similar magnitude event in the future.

6-5. PERSONNEL PROTECTION

The most current governing criteria for personnel protection is defined in reference 10. This guidance requires personnel be protected from fragments exceeding 58 foot-pounds of energy and overpressure exceeding 2.3 psi. This guidance did not exist at the time the Milan design and construction were performed. Although not in compliance with this more recent criteria, the Milan building and cubicle did in effect provide a high degree of protection for operating personnel. The new aluminum roof of the building will essentially eliminate the secondary fragment risk experienced in this incident. The only risk to personnel appears to be that of temporary threshold shift and possible threshold eardrum rupture.

APPENDIX A

REFERENCES

APPENDIX A

REFERENCES

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